Chapter 1

STUDY AREA AND NETWORK DEFINITION

The primary study area for this research is the state of Indiana and its ninety-two counties. A map of the state and its counties appears on the following page (Figure 1.1) and may be useful for reference in relation to some of the data presented later in this report. While the flows to, from, and between these counties are of interest, we can not look only at these; the analysis cannot be limited to intrastate flows.

A significant amount of the commodity traffic in Indiana has neither an origin nor destination in the state, but instead represents goods or materials that are passing through the state. As the 1998 state's 1998 automobile license plate proclaims, Indiana is the "crossroads of America." This overhead traffic may contribute little to the state's economy, but it adds to urban congestion, air pollution, wear and tear on the highways, and rail traffic. Therefore, what happens beyond the state's borders must also be examined here. As a result, this study includes, in addition to the 92 counties of Indiana, several major terminals outside the state. The latter group consists of 48 nodes representing the contiguous 47 states (excluding Indiana, since it is represented as a series of 92 areas) and the District of Columbia, as well as additional nodes for contiguous states: two for Ohio, and one in Illinois, Kentucky, and Michigan.

A transport network consists of nodes and route segments. There are actually four major transport networks that serve the state: the highway system, the railway system, the air transport system and the waterway network. This study is concerned primarily with the highway and railway systems. Flows on the other networks are considered implicitly if motor carriers or rail are used in part of the movement.

The Highway Network

During Phase 1 of this project the highway network used for flow analysis was the 1992 digital network developed for the Federal Highway Administration (FHWA) by the Oak Ridge National Laboratory. This network was based on TIGER (topographically integrated geographic encoding and referencing) files. The digital network also included a considerable amount of attribute data, e.g., length, speed, travel time, and so forth. Detection of border effects during
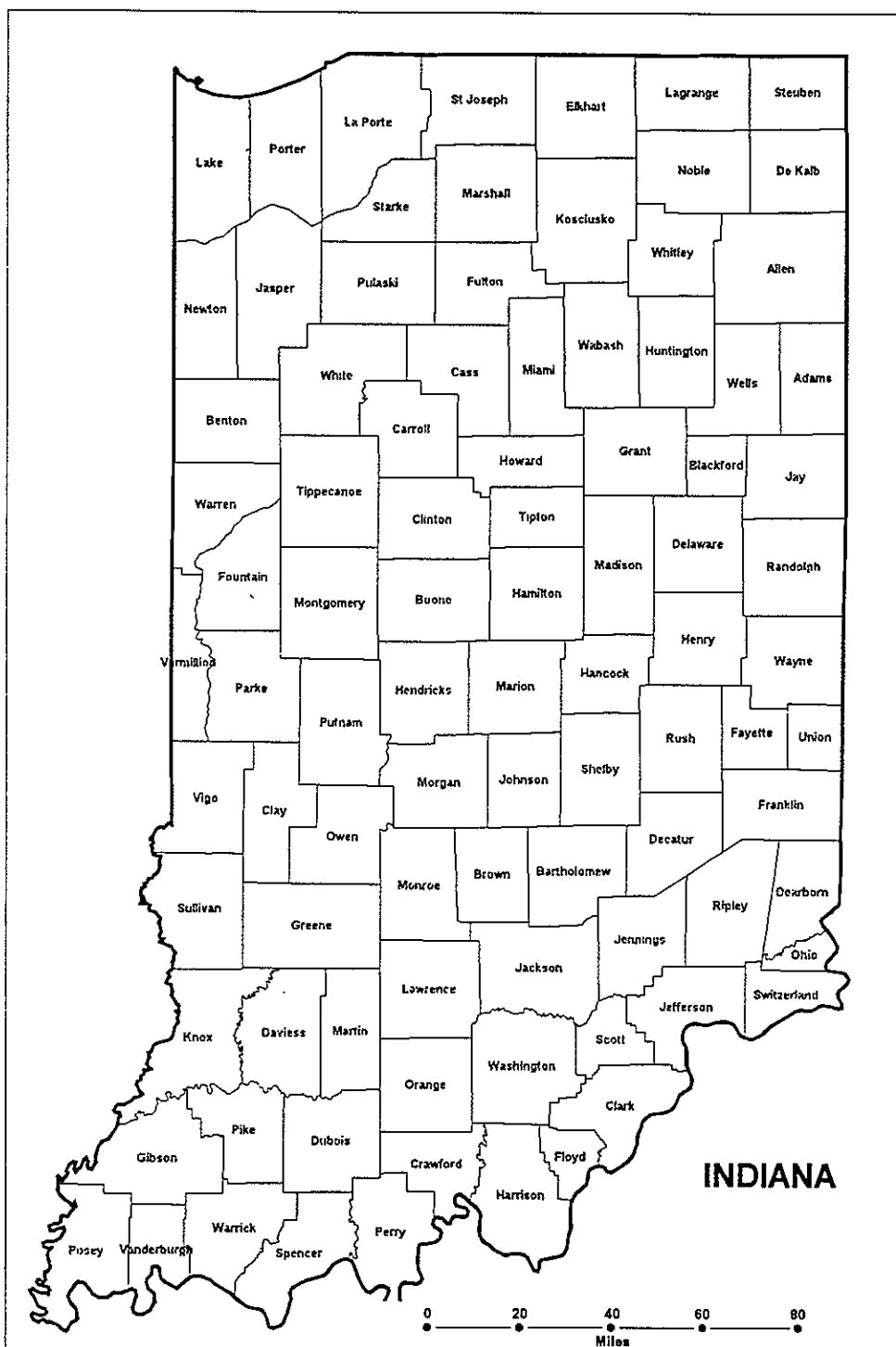
Figure 1.1 The Counties of Indiana

flow assignments led the study staff to use a large circular ring of highways centered on Indianapolis and extending out 200 miles. It was believed that the use of such a ring would eliminate the aforementioned boundary effects.

This Phase 2 study uses a similar national highway network in digital form. It also makes use of the circular ring of highways to eliminate bias attributable to the state boundary. However, the state portion of the highway network differs significantly from the Phase 1 digital network.

The Indiana Department of Transportation wanted this project to use a much more detailed state highway network than was available in a compatible format at the time the project began. The detailed network of interest included the links in the State Roadway Inventory [1]. This database contains a wealth of information on links of the state's highways, but there were certain technical problems that had to be overcome before the network could be used within TransCAD, the transport GIS technology adopted for the project [2]. Two of the major problems encountered were that (1) the state's digital highway network was not in a format compatible with the format used by TransCAD, and (2) the connectivity of the state's network was erroneous. On this latter point a word of explanation may be in order. All that is meant by connectivity is that the links are connected to each other allowing movement to take place from one link to the next. This means the endnode of one link must also be the endnode of a second link, otherwise the links will never touch each other and movement will not be possible. Quite often links appear to be connected on maps, but if we enlarge the map sufficiently we find that the links never really touch each other. Resolving these problems took considerable time. After several false starts during the fall of 1996 a digital highway network for Indiana was received.

Preliminary evaluation of the network revealed that it had significant connectivity problems within Indiana. Programs were written by the project staff to check the network for breaks. In effect, the programs examined all endnodes and assessed whether they were connected to other endnodes less than twice. If so, this would indicate a break in the network. Some of these would be expected, e.g., where a highway goes to a state boundary and stops, but those in the middle of the state usually signaled a connectivity break. These were repaired usually by extending existing links to close the break.

In order to use only part of the FHWA network and all of the "new" Indiana highway network, the Indiana portion of the FHWA network had to be removed. In addition, the attributes and geographic data for both networks had to be put into the same format. The attribute data were kept to a minimum and included only those items such as link length, speed, travel time, and highway name, for which comparable and complete data were available in both the FHWA and Indiana network databases.

After a few false starts and network revisions the Indiana digital state highway network was "woven" into the FHWA digital national highway network. If one were concerned only with

displaying a map of the FHWA and state highway networks, this could be accomplished with most GIS (geographical information systems) programs available. The two networks could be displayed as two different layers in the GIS or the files could be merged and displayed as a single layer. Once again, for mapping this is all that would have to be done. However, if the analysis is to assign traffic to links of the network connecting all different parts of the mapped surface, then the topology (connectivity) of the map must be correct. In this case, topology is making sure that shipments from all nodes to all nodes over the links of the network are possible. For example, all the border links of the Indiana highway network must be joined to links of the FHWA national highway network used here. Should that not be the case, there would be no flow between the nation and this state. Flows would not even pass over the state's links moving from Illinois to Ohio, but would move through Illinois and Kentucky into Ohio, or possibly north to Michigan's upper peninsula and then down through that state into Ohio. It would be as if Indiana had no highways, which from a computational and assignment perspective, it would not. Therefore, the "weaving" of the networks is critical if the new network is to be used later for traffic assignment as this one was.

As a check the program noted earlier for identifying breaks in the Indiana highway network was rerun on the merged highway system to identify any Indiana links that were not connected to the FHWA national highway system. To the surprise of the project staff the program identified several breaks, not in the area where the two networks merged, but in other parts of the FHWA digital national highway network. The breaks were very significant, e.g., all Interstate Highways from California into Arizona were broken, it was impossible to leave Florida via any of their Interstate Highway links, and several neighboring states in the Midwest had breaks in their Interstate Highway links. All of the breaks were fixed before the analysis continued.

The FHWA digital network used was the most complete available in terms of attribute data, when the project began. It is believed this is still the case although a new network is in preparation. One wonders how many states have performed analyses with this network that would clearly give erroneous results. Such a network should never have been released by FHWA if it had so many faults since there is a tendency to accept these federally issued digital networks as accurate.

After all of the corrections and modifications noted above, the resulting network consisted of 34,154 links, 31,557 nodes and 70,620 miles of highway. Of these amounts, 15,074 links, 14,330 nodes, and 11,319 miles of highway network were for these elements of Indiana's State Roadway Inventory. The network resulting from connecting these two networks is displayed in Figure 1.2. The map also displays the location of the highway centroids which were used to represent the various states of the U.S. and counties of Indiana. Figure 1.3 is a map of only the Indiana portion of the digital highway network used here. The 145 nodes (centroids) used for the highway network are identified in Table 1.1. along with their identification number, longitude, latitude, and name.
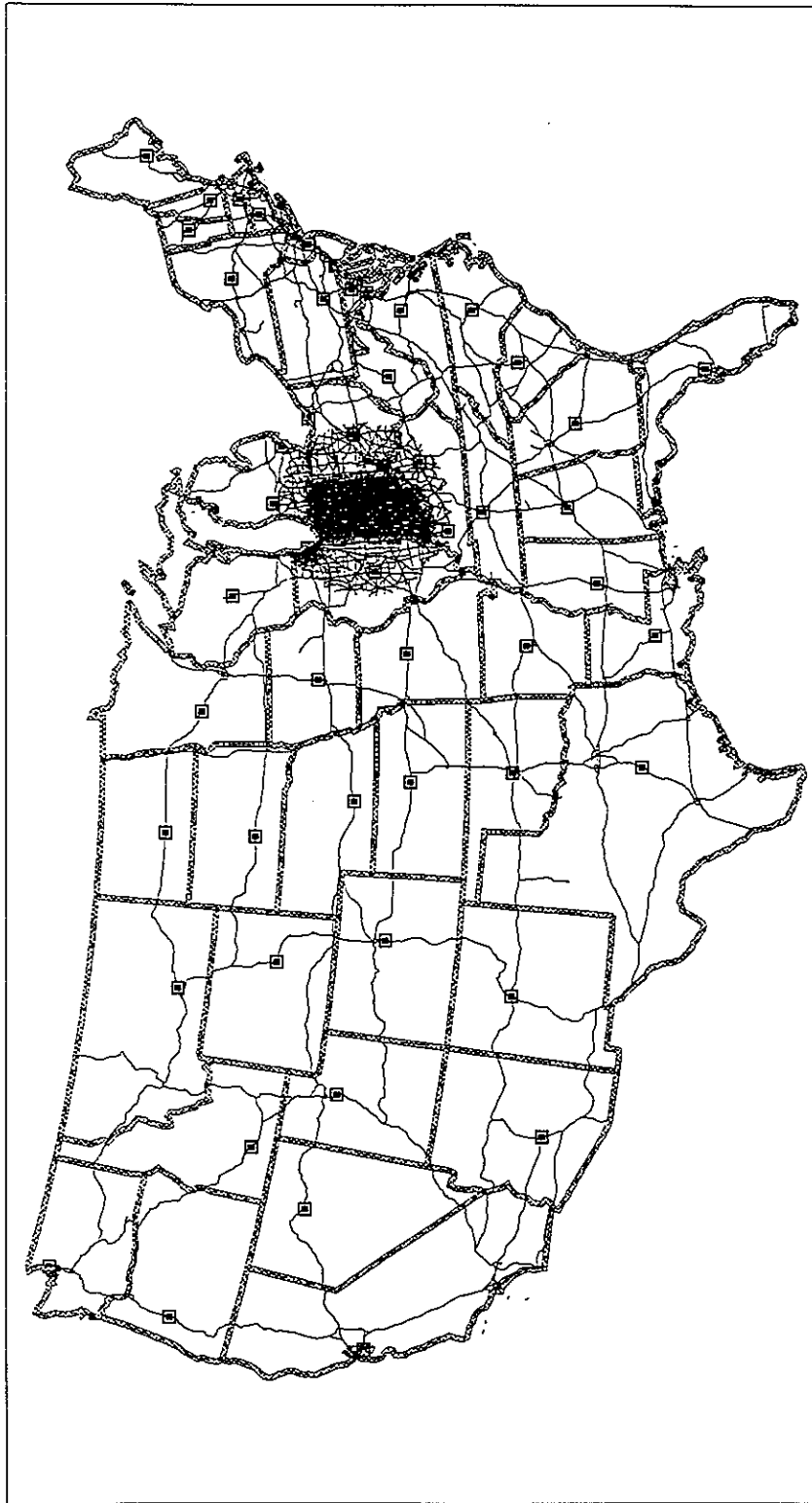

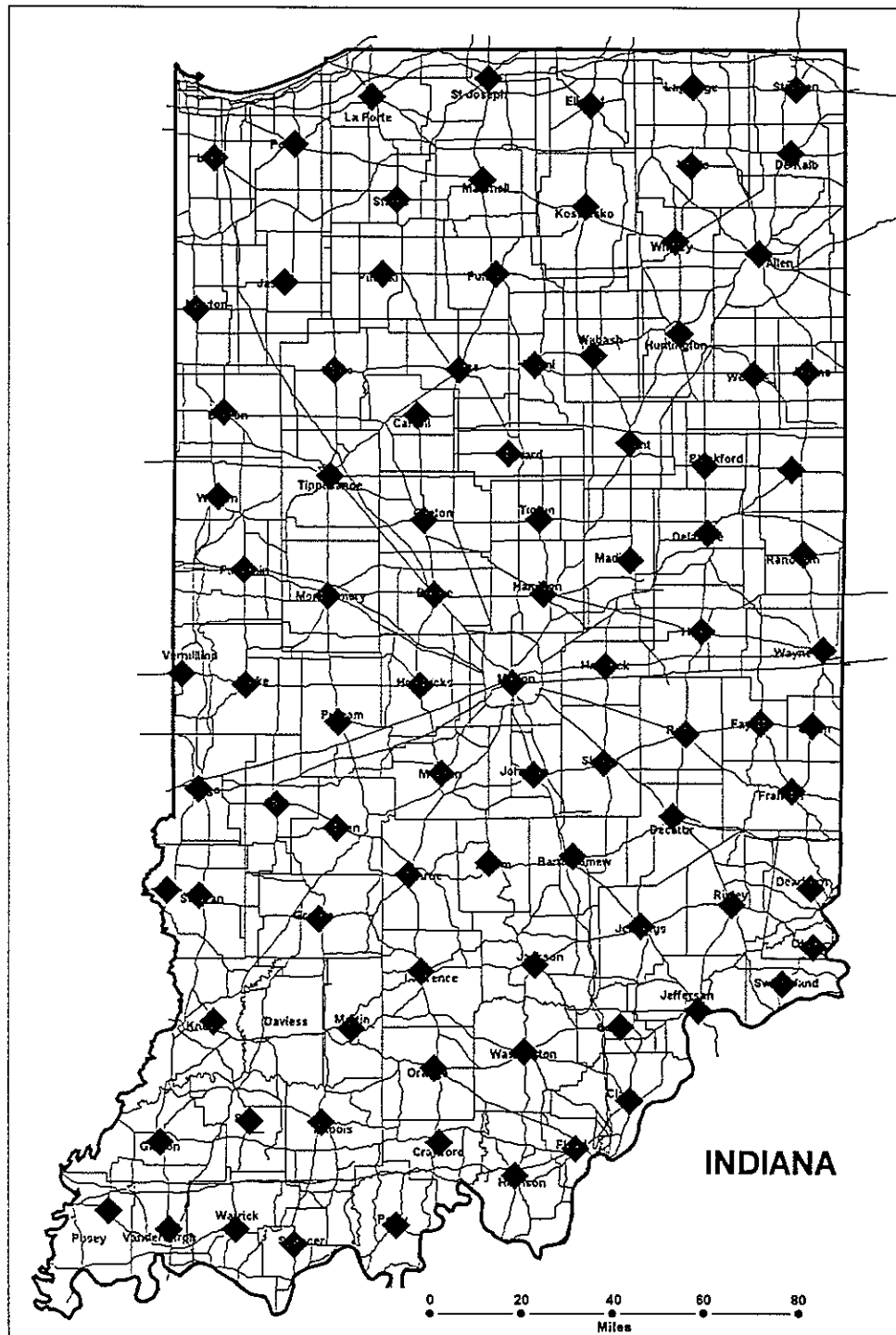Figure 1.2 Digital Highway Network - United States

Figure 1.3 Digital Highway Network - Indiana Portion

Table 1.1. Highway Nodes, Identification Numbers, Names, Longitude and Latitude

25375	Alabama	-87001450	33365780
25611	Arizona	-112037048	33448071
21974	Arkansas	-92408600	38959728
25777	California	-122092819	37644886
26345	Colorado	-10460497	39380070
31177	Connecticut	-72658195	41751236
30101	Delaware	-75603958	39704002
30077	District of Columbia	-77024315	38882244
21644	Florida	-82323914	28325239
27569	Georgia	-83733505	32833076
20574	Idaho	-114702713	42766361
17770	Illinois - north	-87714119	41994698
14633	Illinois - south	-88977463	39847240
03836	Indiana - Adams	-84953967	40744473
14196	Indiana - Allen	-85148587	41118175
11673	Indiana - Bartholomew	-85903035	39222601
08068	Indiana - Benton	-87326211	40618931
13110	Indiana - Blackford	-85370096	40451196
01855	Indiana - Boone	-86469084	40046711
07041	Indiana - Brown	-86247071	39203114
09536	Indiana - Carroll	-86539242	40608626
07691	Indiana - Cass	-86573053	39164669
11319	Indiana - Clark	-85671152	38453826
04894	Indiana - Clay	-87110776	39386469

06941	Indiana - Perry	-86620766	38061157
04384	Indiana - Pike	-87217829	38391349
08451	Indiana - Porter	-87036379	41461809
05970	Indiana - Posey	-87789903	38110515
10483	Indiana -Pulaski	-86679595	41055577
05652	Indiana - Putnam	-86859290	39643906
02055	Indiana - Randolph	-84966811	40172013
11629	Indiana - Ripley	-85256717	39069851
03024	Indiana - Rush	-85444638	39608347
10275	Indiana - St Joseph	-86249850	41667982
11298	Indiana - Scott	-85709914	38686226
11809	Indiana - Shelby	-85776982	39517418
05003	Indiana - Spencer	-87036571	38002938
08237	Indiana - Starke	-86620661	41288219
12556	Indiana - Steuben	-84999421	41635083
04637	Indiana - Sullivan	-87425050	39101031
11245	Indiana - Switzerland	-85053397	38822028
09837	Indiana - Tippecanoe	-86893161	40418129
04231	Indiana - Tipton	-86040879	40282280
03213	Indiana - Union	-84930931	39634368
06125	Indiana - Vanderburgh	-87544332	38050425
06732	Indiana - Vermillion	-87494652	39796918
06623	Indiana Vigo	-87427728	39434457
12735	Indiana - Wabash	-85820532	40796973
01439	Indiana - Warren	-87347490	40351615

06210	Indiana - Warrick	-87274270	38049971
00570	Indiana - Washington	-86100700	38608602
02008	Indiana - Wayne	-84888193	39872212
13800	Indiana - Wells	-85171534	40737703
08146	Indiana - White	-86875335	40749237
04087	Indiana - Whitley	-85488392	41156847
22080	Iowa	-93570801	41877880
22354	Kansas	-98061325	38870941
16105	Kentucky - west	-87498459	37348721
16817	Kentucky - east	-84508781	38050552
21018	Louisiana	-92177246	30768177
31646	Maine	-68780128	44785629
30036	Maryland	-76745453	39348721
31276	Massachusetts	-71803101	42245346
28889	Michigan - west	-85590714	42972660
30252	Michigan - east	-83085312	42483574
22743	Minnesota	-94952209	45720459
21341	Mississippi	-90068771	32611351
22043	Missouri	-92544838	38959728
20912	Montana	-107989990	45986740
22288	Nebraska	-98951050	40686829
20255	Nevada	-116904617	40619709
31469	New Hampshire	-71526314	43193218
24764	New Jersey	-74451385	40404953
26460	New Mexico	-106635727	35085262

01888	Indiana - Clinton	-86510932	40279584
00374	Indiana - Crawford	-86448299	38321404
04558	Indiana - Daviess	-87555899	39117615
10940	Indiana - Dearborn	-84937265	39122123
11933	Indiana - Decatur	-85497244	39347288
12521	Indiana - DeKalb	-85019938	41433312
13423	Indiana - Delaware	-85356645	-40238854
05795	Indiana - Dubois	-86927213	38387268
14114	Indiana - Elkhart	-85834230	41584910
03220	Indiana - Fayette	-85142406	39640097
02636	Indiana - Floyd	-85890756	38303455
08872	Indiana - Fountain	-87242952	40124244
03172	Indiana - Franklin	-85012472	39427393
02330	Indiana - Fulton	-86217424	41055096
06287	Indiana - Gibson	-87582319	38325040
13545	Indiana - Grant	-85673310	40520759
00670	Indiana - Greene	-86937418	39026818
00126	Indiana - Hamilton	-86023308	40046949
11908	Indiana - Hancock	-85769989	39821176
00291	Indiana - Harrison	-86136789	38218227
00753	Indiana - Hendricks	-86526276	39760715
12205	Indiana - Henry	-85381696	39931634
02087	Indiana - Howard	-86167401	40487727
12159	Indiana - Huntington	-85470687	40864580
00829	Indiana - Jackson	-86057140	38880308

09227	Indiana - Jasper	-87078124	41027313
12452	Indian - Jay	-85015618	40438266
02751	Indiana - Jefferson	-85392979	38738783
02912	Indiana - Jennings	-85627011	39003602
07355	Indiana - Johnson	-86063722	39480040
04362	Indiana - Knox	-87365299	38701941
03989	Indiana - Kosciusko	-85852545	41266345
12900	Indiana - Lagrange	-85417783	41642410
08981	Indiana - Lake	-87364515	41416929
10282	Indiana - LaPorte	-86721856	41610473
05528	Indiana - Lawrence	-86522335	38860978
13671	Indiana - Madison	-85672046	40153712
01192	Indiana - Marion	-86150306	39766680
02318	Indiana - Marshall	-86273639	41350024
05124	Indiana - Martin	-86805100	38680895
02273	Indiana - Miami	-86059999	40766532
07161	Indiana - Monroe	-86573053	39164669
07664	Indiana - Montgomery	-86901226	40042734
00948	Indiana - Morgan	-86439723	39482832
08399	Indiana - Newton	-87435513	40940673
12877	Indiana - Noble	-85423933	41395492
03377	Indiana - Ohio	-84925942	38937571
05350	Indiana - Orange	-86468058	38556489
05471	Indiana - Owen	-86865692	39312617
00164	Indiana - Parke	-87236190	39762655

29054	New York	-75205978	43111839
24237	North Carolina	-78561661	35608601
19670	North Dakota	-100709396	46835499
29431	Ohio - north	-82021896	41464378
18974	Ohio - central	-82987137	40087891
17175	Ohio - south	-84517738	39221035
27879	Oklahoma	-97575577	35511169
25960	Oregon	-123048782	44044090
30129	Pennsylvania	-76921181	40316608
31188	Rhode Island	-71490356	41666729
23926	South Carolina	-80994827	34404919
19361	South Dakota	-100705467	43883072
28659	Tennessee	-86857758	36152271
21115	Texas	-97268593	31266665
26255	Utah	-111724930	40311611
24899	Vermont	-72608063	44114300
23751	Virginia	-78052666	37902699
20021	Washington	-122303139	48297894
24113	West Virginia	-80740097	38656830
23424	Wisconsin	-89595581	44567215
26563	Wyoming	-106270157	42853634

The Railway Network

At the time of the Phase 1 study there was no generally accessible railway network in digital form. As a result that study used TIGER files to define a rail network within the state of Indiana. Connectivity to the remainder of the U.S. was accomplished using an abstract graph of these connections. This approach was reasonable for the time. In the interim the Federal Railroad Administration (FRA) has released a network of the rail system of the United States in digital form.

The rail network developed by the FRA is based on topographic maps with a scale of 1:2,000,000. The accuracy of such a map is approximately 1,200 meters, about three quarters of a mile, in terms of root-mean square. There are other networks available at a scale of 1:100,000, but these did not contain some of the data necessary for analysis purposes in this study. For this reason the 1:2,000,000 network was used here. It consists of approximately 16,000 links and 11,500 nodes (see Figure 1.4).

A little more detail can be mapped for Indiana, including ownership of the rail lines (see Figure 1.5). This is a very dynamic area and as the tracks of the Consolidated Rail Corporation (Conrail) are sold to the Norfolk Southern and CSX corporations in the near future ownership of these lines will change.

Among the attribute data available in this network are a link identification code, origin and destination end nodes for each link, owner of the link, abandonment status, and traffic density. It was this latter variable that was critical to later analysis. It is used as one of the key variables in assigning traffic to the rail system.

Partly as a precaution the connectivity program used earlier was rerun to assess this aspect of the FRA digital rail system. However, rail networks are different than highway networks in terms of isolated nodes. Although one rarely sees naturally occurring isolated nodes in a highway network, these are very common in rail networks where every branch line ends with such an isolated node. Running the program for the rail network revealed a substantial number of these across the country, as expected. However, there is a section of the central United States where no isolated endnodes were found. This goes through Indiana and even where there are obviously branch lines with isolated end nodes, these were not identified by the program. The program was checked for accuracy and was found to be without fault. At the same time isolated end nodes on branch lines were not being identified, which meant that these end nodes were connected to two nodes. The only way this could occur is if the data were appearing twice in the database. A simple sort of all link endnodes revealed that a substantial amount of the network had been entered twice by FRA or their contractors. This problem was also corrected.
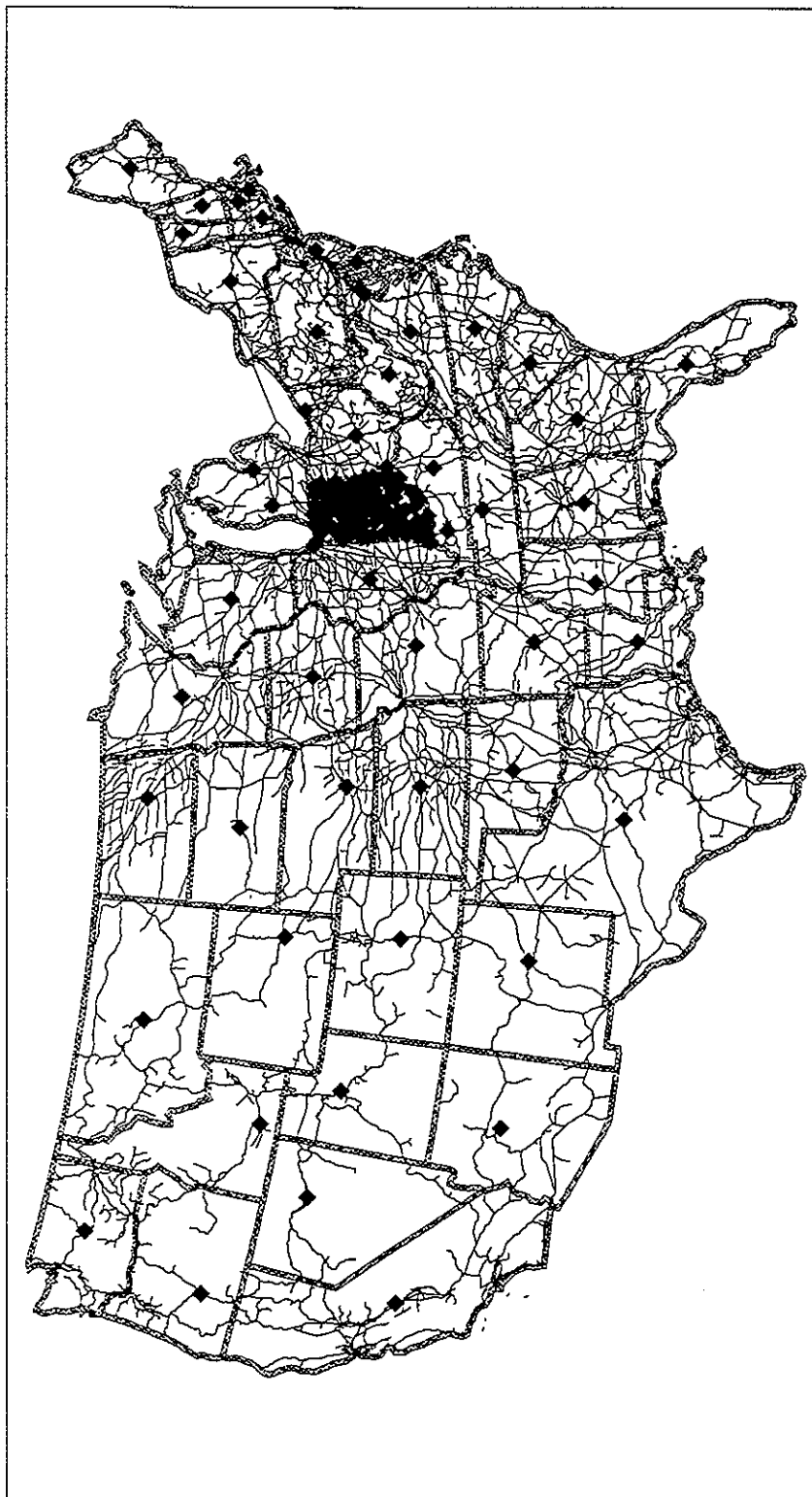
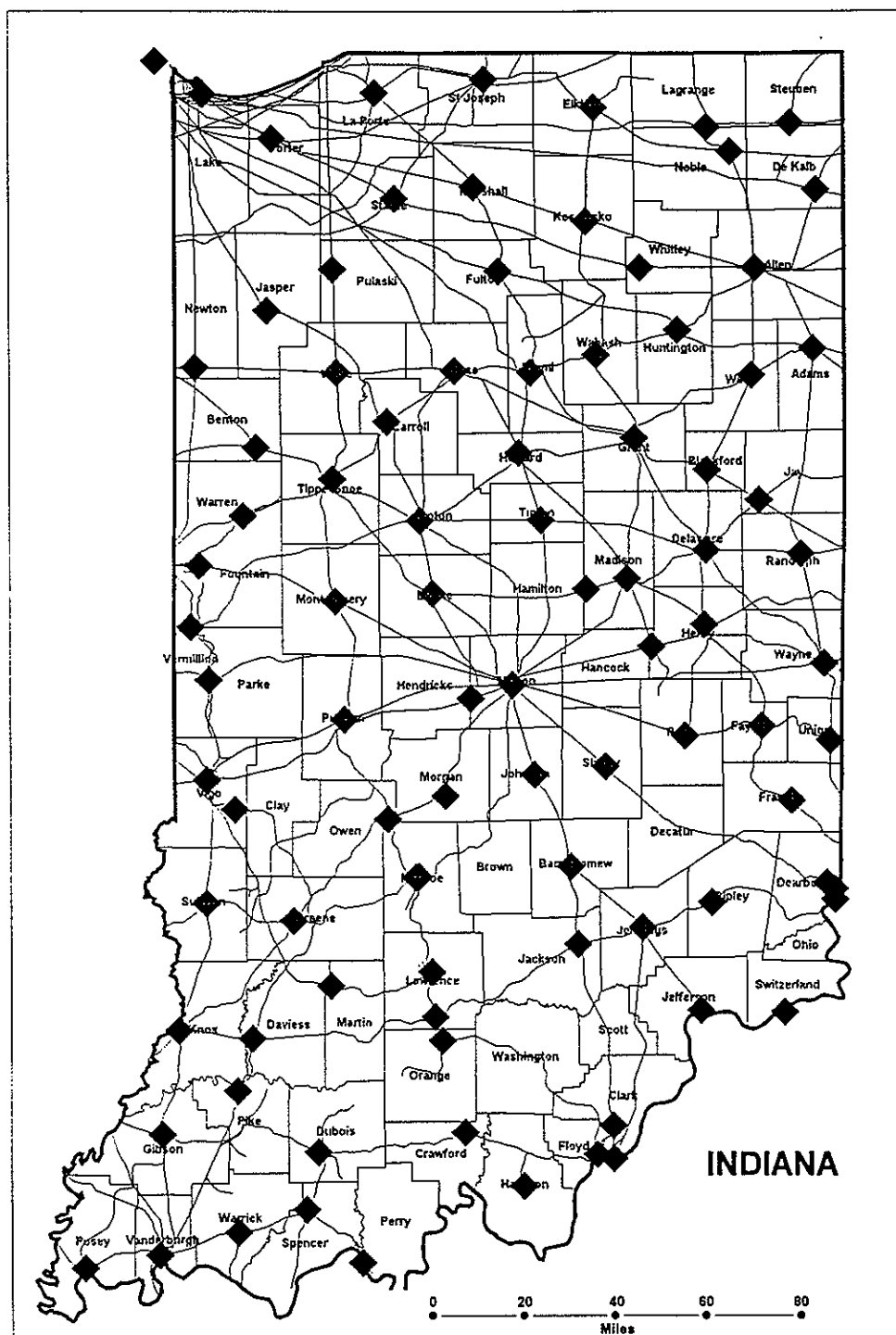Figure 1.4 Digital Railway Network - United States

Figure 1.5 Digital Railway Network - Indiana Portion

The 145 longitudes and latitudes of the nodes (centroids) of the railway network used here are displayed in Table 1.2. In some cases the node for a county in Indiana is not located in that county. This is because the county has no rail service or the digitized rail network has no node in the county. Keeping with reality the assumption was made that these places would be served by a nearby rail line with the final portion of the move occurring by truck.

Other Networks

Digital representations of the air and waterway networks were also considered for inclusion here at the beginning of the project, but changes in the design of the project by the study advisory committee made these superfluous. The waterway network is used primarily to move bulk raw materials, such as grains and minerals beyond the borders of Indiana, i.e., the Indiana portion of the move is by rail or motor carrier and was implicitly covered by the study. The air transport system moves some freight, but it is primarily a passenger system. Intercity air travel was also dropped from this phase of the study and this resulted in the dropping of the air transport network. In addition, as is true of waterways, the Indiana portion of air freight shipments is included here as a highway move.

Conclusion

After corrections for errors the highway and rail networks used here are among the best available for regional transport planning purposes. It would be desirable to have more complete attribute data available in both networks, but this is beyond the scope of the present study. It is also true that correcting the two network databases were beyond the scope of this study, but these were actually preventing the study from being completed.

The digital rail network could be increased to the 1:100,000 scale. Such a network already exists, but it has virtually no attribute data. It is reasonable to assume that FRA will increase the amount of attribute data in this network database in the near future.

Table 1.2. Railway Nodes, Identification Numbers, Names, Longitude and Latitude

679608	Alabama	-86872877	32795406
243152	Arizona	-112055000	34792780
939180	Arkansas	-92273060	34737780
94488	California	-120013890	36974720
403437	Colorado	-104810550	38869170
1990777	Connecticut	-72772500	41618330
1867145	Delaware	-75576670	38928330
1860688	District of Columbia	-77004008	38901899
730522	Florida	-82035550	28867220
764752	Georgia	-83555560	32704440
277697	Idaho	-113677220	42600560
1403247	Illinois - north	-87599170	41733610
1277657	Illinois - south	-89288060	40003610
1454441	Indiana - Adams	-84926390	40827500
1459831	Indiana - Allen	-85161110	41083330
1430919	Indiana - Bartholomew	-85916110	39197220
1391298	Indiana - Benton	-87193890	40517220
1449897	Indiana - Blackford	-85356390	40444440
1415250	Indiana - Boone	-86477500	40057220
1378411	Indiana - Brown	-86533890	39165280
1412020	Indiana - Carroll	-86661110	40596940
1415298	Indiana - Cass	-86385560	40758060
1427425	Indiana - Clark	-85741862	38278012
1374674	Indiana - Clay	-87285000	39378890

1412004	Indiana - Clinton	-86528050	40285280
1378251	Indiana - Crawford	-86348050	38360000
1369860	Indiana - Daviess	-87215550	38658890
1437115	Indiana - Dearborn	-84842356	39127172
1431039	Indiana - Decatur	-84872500	39144440
1459919	Indiana - DeKalb	-84912220	41326950
1454369	Indiana - Delaware	-85361110	40193610
1369884	Indiana - Dubois	-86947780	38298330
1454521	Indiana - Elkhart	-85813330	41585830
1431055	Indiana - Fayette	-85135830	39641110
1378331	Indiana - Floyd	-85809450	38290000
1391226	Indiana - Fountain	-87425830	40146110
1445057	Indiana - Franklin	-85015000	39404450
1422726	Indiana - Fulton	-86205000	41071670
1365891	Indiana - Gibson	-87580830	38354720
1449841	Indiana - Grant	-85651660	40545560
1370060	Indiana - Greene	-87048060	39027780
1449769	Indiana - Hamilton	-85851110	40070000
1431015	Indiana - Hancock	-84883330	39835560
1378291	Indiana - Harrison	-86107780	38189720
1378491	Indiana - Hendricks	-86321699	39725853
1449921	Indiana - Henry	-85368330	39958060
1415290	Indiana - Howard	-86122780	40498890
1449905	Indiana - Huntington	-85474720	40885000
1378467	Indiana - Jackson	-85885280	38952780

1405559	Indiana - Jasper	-87147500	40948060
1454385	Indiana - Jay	-85145840	40349720
1430943	Indiana - Jefferson	-85386836	38745996
1430911	Indiana - Jennings	-85623890	39005000
1385289	Indiana - Johnson	-86062500	39487500
1366019	Indiana - Knox	-87513050	38684720
1422750	Indiana - Kosciusko	-85848890	41230000
1459935	Indiana - Lagrange	-85354450	41524720
1409342	Indiana - Lake	-87408060	41629440
1419815	Indiana - LaPorte	-86706950	41631940
1378323	Indiana - Lawrence	-86480830	38866660
1449761	Indiana - Madison	-85682250	40103126
1378483	Indiana - Marion	-86152220	39770000
1422694	Indiana - Marshall	-86305000	41337500
1378339	Indiana - Martin	-86894170	38824440
1415338	Indiana - Miami	-86075280	40751950
1378395	Indiana - Monroe	-86547230	39163020
1411972	Indiana - Montgomery	-86872500	40032220
1378451	Indiana - Morgan	-86424720	39419450
1391322	Indiana - Newton	-87440830	40770560
1459735	Indiana - Noble	-85261110	41448890
1437107	Indiana - Ohio	-84838893	39093558
1378307	Indiana - Orange	-86441110	38650280
1378379	Indiana - Owen	-86659450	39348330
1374746	Indiana - Parke	-87388050	39786390

1374826	Indiana - Perry	-86769450	37951390
1369836	Indiana - Pike	-87277780	38493060
1410589	Indiana - Porter	-87126110	41489720
1363101	Indiana - Posey	-87895519	37937228
1415362	Indiana - Pulaski	-86880840	41079170
1374770	Indiana - Putnam	-86837220	39661670
1454401	Indiana - Randolph	-84977220	40181110
1430951	Indiana - Ripley	-85341110	39083890
1430991	Indiana - Rush	-85448610	39610000
1422806	Indiana - St Joseph	-86261390	41675560
1427441	Indiana - Scott	-85744720	38381390
1430959	Indiana - Shelby	-85773610	39513050
1374794	Indiana - Spencer	-86995830	38118060
1415434	Indiana - Starke	-86626950	41301390
1459951	Indiana - Steuben	-85015231	41537597
1370012	Indiana - Sullivan	-87399720	39082780
1430895	Indiana - Switzerland	-85045000	38739170
1391274	Indiana - Tippecanoe	-86882230	40418060
1415274	Indiana - Tipton	-86034720	40286670
1431071	Indiana - Union	-84859170	39594170
1363205	Indiana - Vanderburgh	-87592602	37977215
1388072	Indiana - Vermillion	-87459720	39952500
1374658	Indiana - Vigo	-87396940	39471670
1449881	Indiana - Wabash	-85806110	40807780
1391266	Indiana - Warren	-87248528	40303011

1365955	Indiana - Warrick	-87274440	38047500
1374850	Indiana - Washington	-86468890	38725830
1445105	Indiana - Wayne	-84883330	39835560
1454409	Indiana - Wells	-85175830	40744450
1412012	Indiana - White	-86865840	40753610
1454473	Indiana - Whitley	-85628050	41081670
1107371	Iowa	-93447414	42027780
862094	Kansas	-98243890	38513050
1358953	Kentucky - east	-84801110	37585280
1323859	Kentucky - west	-87492770	37337220
596679	Louisiana	-92418050	31330830
2060946	Maine	-69018060	4531670
1863233	Maryland	-76775000	39009170
2026476	Massachusetts	-71795000	42257220
1569778	Michigan - east	-83932220	43439170
1558742	Michigan - west	-85660000	42974720
1142580	Minnesota	-94225000	46348610
650121	Mississippi	-90039720	32615000
997476	Missouri	-92238050	38618060
327607	Montana	-109798060	46926670
886260	Nebraska	-98322220	40931950
232406	Nevada	-116466288	40593036
2033555	New Hampshire	-71583890	43451950
1961110	New Jersey	-74708340	40152780
337744	New Mexico	-105213470	34610695

2002329	New York	-75234440	43110550
1769102	North Carolina	-79285840	35565560
1038047	North Dakota	-99122220	47458330
1661951	Ohio - central	-82996670	39972220
1740527	Ohio - north	-81610280	41488610
1443420	Ohio - south	-84536110	39115550
808526	Oklahoma	-97511950	35480000
145996	Oregon	-121777780	43215560
1850726	Pennsylvania	-78239720	40672780
1996059	Rhode Island	-71439720	41808330
1621721	South Carolina	-81049450	33973060
461272	South Dakota	-100348890	44371110
1323995	Tennessee	-86748340	36126670
506462	Texas	-99365840	31782500
254561	Utah	-111618060	40157780
2021471	Vermont	-72612780	44271110
1790836	Virginia	-78938330	37668610
198082	Washington	-120327220	47450280
1719825	West Virginia	-80586390	38588610
1518461	Wisconsin	-89754450	44583330
439681	Wyoming	-105201110	42651670

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